AC 2012-3605: HMI DESIGN: AN ANALYSIS OF A GOOD DISPLAY FOR SEAMLESS INTEGRATION BETWEEN USER UNDERSTANDING AND AUTOMATIC CONTROLS

Prof. Akram Hossain, Purdue University, Calumet

Akram Hossain is a professor in the Department of Engineering Technology and Director of the Center for Packaging Machinery Industry at Purdue University Calumet, Hammond, Ind. He worked eight years in industry at various capacities. He is working with Purdue University Calumet for the past 24 years. He consults for industry on process control, packaging machinery system control, and related disciplines. He is a Senior Member of IEEE. He served in IEEE/Industry Application Society for 15 years at various capacities. He served as chair of manufacturing Systems Development Applications Department of IEEE/IAS. He authored more than 25 refereed journal and conference publications. In 2009, he as PI received NSF-CCLI grant entitled A Mechatronics Curriculum and Packaging Automation Laboratory Facility. In 2010, he as Co-PI received NSF-ATE grant entitled Meeting Workforce Needs for Mechatronics Technicians. From 2003 through 2006, he was involved with Argonne National Laboratory, Argonne, Ill., in developing direct computer control for hydrogen powered automotives. He is also involved in several direct computer control and wireless process control related research projects. His interests are in the area of industrial transducer, industrial process control, modeling and simulation of mechatronics devices and systems, wireless controls, statistical process control, computer-aided design and fabrication of printed circuit board, programmable logic controllers, programmable logic devices, and renewable energy-related projects.

Ms. Tanima Zaman, Purdue University Calumet

Tanima Zaman is a graduate staff member under the Department of Engineering Technology at Purdue University Calumet, Hammond, Ind. Currently, she is pursuing her master's degree in mechatronics engineering technology at Purdue University, Calumet. She has obtained a bachelor's degree in electrical and electronic engineering from East West University, Dhaka, Bangladesh. Her interests are in the area of modeling and simulation of mechatronics devices and systems, designing human machine interfaces, statistical process control, computer-aided design, and fabrication of printed circuit board, programmable logic controllers.

HMI Design: An Analysis of a Good Display for Seamless Integration Between User Understanding and Automatic Controls

Abstract:

In process automation industry operator interface is usually a Human Machine Interface Unit (HMI). HMI plays a significant role in creating a friendly visual environment between the user and the technology. It is considered to be the window to the automation control system. Controlling through finger touch has replaced the use of hammers and manual switches enormously. With the increasing application of HMIs in industry, a good number of software tools are being introduced and the competiveness in designing HMI displays is increasing tremendously. This paper focuses on various important aspects in designing HMI displays to meet the quality criteria such as ease and seamlessness in user understanding, efficiency of learning the HMI design software tools and satisfaction of the operators to control large systems. These aspects consist of issues with screen layout, color representation, graphics and pictures, text and data values, alarms, navigation, control and so on. The scope of this paper is to gain knowledge about how to incorporate as much information in one limited display monitor, by multiple numbers of pages in a graphical hierarchy. This is needed to provide an operator with clear visual understandings of process operations with both moderate and complex applications. This paper also consists of appropriate guidelines for designing an HMI unit in a most efficient way. As examples we designed an HMI unit intended to control a packaging machine coupled with Allen-Bradley CompactLogix and MicroLogix Programmable Logic Controllers (PLC) systems.

Introduction:

Major portion of the operations in modern manufacturing industries are performed by the implementation of automation technology. In order to achieve high productivity from the automated machineries used in the industries at present, the technology is growing more complex, making issues of end-product equipment safety, ease of operation and reducing human error extremely significant. As a result the interaction between human operators and automated machines are becoming more critical. Human machine interfaces (HMIs), enable the operators

for complicated machineries to see, touch and control high stress industrial processes through touch screen displays. As HMI systems are turning to be the principal point of interaction between the user and the machine/process in automation industry, a good HMI display makes this interaction flawless and smooth. On the contrary, a poor HMI design makes it difficult for the operators to have a clear understanding of the machine/process and contributes to reduced systems performance, significant amount of production loss, or even accidents/fatalities at worst.

In the process industry, high performance HMI display design focuses on providing maximum amount of effective information related with a machine/process. There is a misconception that incorporating more raw data means providing more information. In real sense, providing useful data with proper presentation is reflected as information while designing an efficient HMI display. Well-designed HMIs result to visually better system understanding and easy troubleshooting for the operators. Unfortunately, many design engineers do not emphasize on practicing industrial standards while designing HMI displays for controlling complex machineries. Most of the designers have the tendency to design screens with bright colors and complicated graphics (e.g. flashing animated flames, 3D process vessels, spinning pumps/ moving conveyers etc). These kinds of displays make it difficult for the operators to be able to visually understand the overall operational conditions of the process. Not following the specified industrial color codes may result to confusions or misinterpretations of control commands which increase the probability of human errors and may even cause system breakdown/production loss.

As the market is becoming intensively competitive, all of the above aspects along with some other important factors such as, graphical hierarchy in multiple page display, proper system alarm status etc, are critical for designing a operator friendly and efficient HMI unit design.

HMI Touch Panels:
In the present context, most of the companies providing automation machine building solutions are including HMI touch panels as an integral component of their automated systems. Most of the HMI panels have specific design environment software tools provided by the HMI manufacturing company. Rockwell Automation's Allen-Bradley PanelView™ Plus series (AB PanelView™ Plus 600, AB PanelView™ Plus 1000 etc) HMI touch-screens are most commonly

used as operator interfaces in the industry today. Rockwell Automation's FactoryTalk View Studio software allows the engineers to create applications in a single PanelView™ Plus series design environment. These HMI panels are able to successfully communicate with either of Allen-Bradley CompactLogix or MicroLogix PLC (programmable logic controller) series for sophisticated industrial motion controls as well as a significant range of other automation applications[1]. Eaton Cutler-Hammer HMI operator interfaces are designed by Eaton HMISoft software in a very user friendly environment for controlling a wide range of robust industrial automation applications. Schneider Electric's Magelis, Mitsubishi Vision 1000 series, Siemens Simatic Panel, are also equally popular for industrial automation controls applications. Other than the HMI panels mentioned in this paper, there are many other types of human machine interface touch screens that are being used in various industrial applications.

Design Methods for Efficient HMI Displays:

In the automation world, the definition of a good HMI display is not limited within few perfect sentences. Presently, all modern control panels are visual displays, designed in such a way that fulfills a range requirements in order to achieve maximum operational efficiency and minimum or no human errors. While designing an HMI monitor with multiple visual displays, two major factors should always be taken under consideration, (1) the screen must be able to hold operator's attention with maximum display clarity and (2) the design must allow a person with no training or little experience to be able to successfully operate a machine.

In this paper we are focusing on a few fundamental factors critical to HMI touch-screen display design. The objective here is to provide design guidelines to accomplish an effective HMI which will enable its operators to operate in a very user friendly way with maximum operational simplicity.

Screen Layout

Proper screen layout is very important for a good HMI display. Generally, a human operator scans an HMI screen, as any other regular screens, starting from top left corner to right and then down the screen. So, the important objects of a system should be in an area within the page where the operator's attention goes easily. The alarms should be on the top of the page. Any

graphical image object should be on the center left with key data on the center right of the page. It is recommended that start, stop or controls are kept in the lower left side and the navigation on the lower right side of the page. All objects should be highlighted with black outlines.[2]

Color Issues

Before designing an HMI display it is very important to have a very good understanding about how to use colors. Color is a very powerful tool for visual presentations. At the same time it can cause danger in operation if misused. Therefore, choosing the right color for the background, control buttons, alarms, text and other objects is very critical for good HMI design.

- **Background Color**

  Primary colors (red, green, blue) should never be used as background color in an HMI. Although black and white provide good color contrast but using these in background makes the screen look glare. Therefore, these are also not right choice as screen background. For an HMI display background, it is always recommended to use pastel shades such as light grey, light brown etc. These colors are easier to look and provide good contrast for the dark/ brighter colors (i.e. red, yellow, green, blue etc) used for other components in the display page.

  While incorporating multiple pages within one display, it is wise to use multiple shadows for each page so that the operators can visually identify different pages at a glance even from a distance.

- **Display Colors for Objects**

  According to SCADA/HMI Design Standard, there are few colors those specifically should be used for representing certain operations. They are[2]:

  Red→ Stop, Emergency or Prohibition

  Green→Start or Safe Condition

  Yellow→ Warning

  Blue→Mandatory Operation

While designing HMI display it is necessary that these color conventions are strictly maintained and clearly visible to the operators. In addition, these colors should never be used for any other purpose because it can result to misinterpretation or confusion for the operator. Dark colors should not be used on screen in large blocks because they can create complementary color image retention on the retina. [2]

Figure 1 and 2 below shows the difference between HMI screen with bad color selection on the left and proper color selection on the right.[3]
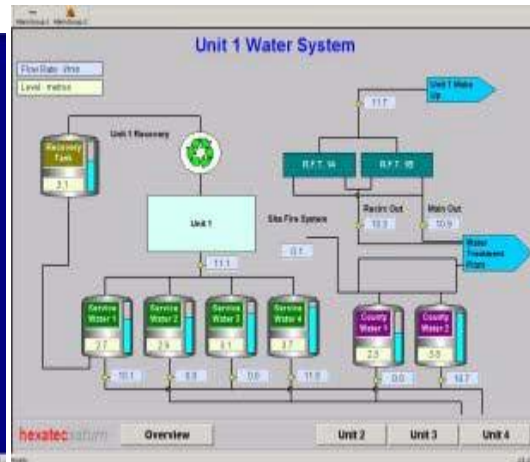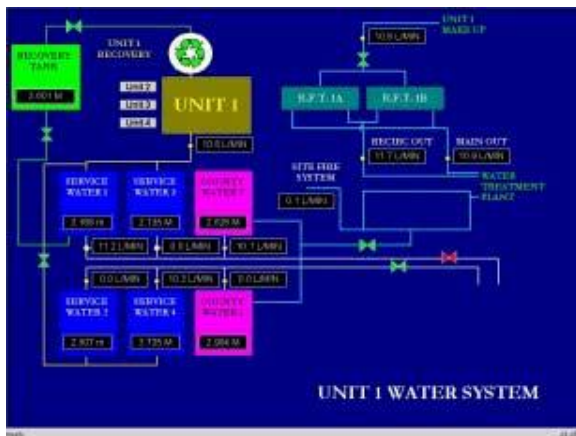

Figure 1: A Bad HMI Color Selection   Figure 2: A Good HMI Color Selection

(Source: A High Performance HMI Handbook)

Graphics and Picture Issues

When it comes to good HMI design, the general conception of using graphics does not work out. An HMI graphics should look "boring" rather than "cute" and "fancy". This means a good HMI graphics will never have big flashing animated lights, 3D vessels with bright colors, spinning pumps or moving conveyors. Putting an exact representation of P&ID or big bright measurement units are worse ideas while designing an HMI Screen. An HMI graphic should always have a gray background. There should be no animation and lots of crossing lines should be avoided, so that the operator does not get detracted from important dynamic data.

Mostly while designing HMI, it is important to include a representation of the complete process flow in the HMI screen. This makes the operators to visualize the plant and identify the locations of the measurements. A good HMI should always have consistent black process flow direction

and the use of color must be limited. An HMI graphics should always include trends so that the operator can easily follow the behavior of a plant and monitor possible excursions. Figures below show a bad HMI graphic and a good HMI graphic[3]:
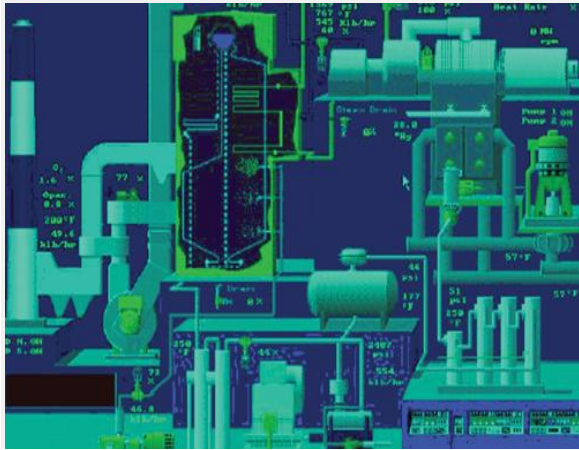

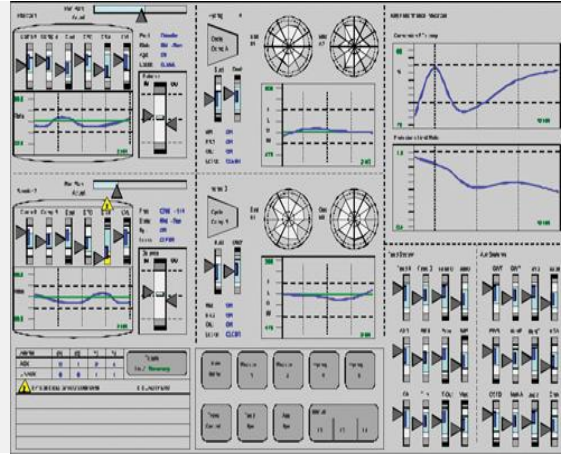**Figure 3: A Poor HMI Graphics**   **Figure 4: A Good HMI Graphics.**

(Source: A High Performance HMI Handbook)

Display Text

Text in an HMI screen is the most versatile way to convey information to the operator. Hence, proper font and color should be used in the display so that an operator can no way have difficulty to read and understand the information. It is always wise to choose fonts which are commonly available in most of the computers, such as Arial, Times New Roman etc. The size of the text should be as such that the operator can read the key information from several feet away without any trouble and all the text should be black. The texts for the heading and labels should be larger than the texts used for buttons and alarms. But too much variation in text size can make the display cluttered and visually confusing for the operators. Limited use of Upper-Case letters and underlines keep the operators from having eye strain. The heading of an HMI and the first letter of the labels should be in upper-case. All the rest of the texts should be in lower case letters. It is better to use underline for the heading. For labels and other texts on screen, sans-serif font is easier to read than serif.

Presenting Data Values

Proper representation of data values of the system is very important for the operator to be able to read and observe important system parameters. The data values should be grouped in areas of an HMI screen. Data values place around pictures are often hard to scan. If an operator needs to

compare between data values then the respective data values should be placed in table next to each other on the screen. In case of multiple data values the units should be mentioned with proper labeling and the data values should be placed in proper order.

It is always preferable to present data graphically. People often can understand and respond to data presented graphically much quicker than they can to data presented alpha-numerically. For example if an analog meter is used for representing some reading, it is much easier to visually get an idea of the value. This is significant to observe continuous changes of the readings. But when a user needs to know an exact value then numerical data is needed to be presented. It is always preferable to avoid unnecessary decimal places. [2]

Alarms and Event

Alarm and event information are vital parts in HMI screen design because it enables the operator to identify system operations and avoid critical situation those may arise during a process. Alarms consider changes in a process or in its control system (e.g. operator action, configuration changes etc) those need to be recorded. While designing an HMI touch-screen, alarms should consist of the following characteristics:

1. **Informative:** No action required, e.g. Process stopped at 11.00 am.
2. **Warning:** Process could "Stop" or could be "Damaged" if no corrective action is taken soon, e.g. Bottle is not oriented accordingly.
3. **Blocking:** The controller takes an action against any risky condition to protect the process and further operation is prevented until the reason is cleared, e.g. "Cup Jam"

An event occurs whenever an operator reacts to alarms or makes any changes to the system. Alarms with different audio effects are often helpful for operators to quickly determine normal process conditions and when an error occurs that needs to be fixed.

Navigation and Controls

Operator of a process should be able to change between HMI pages quickly and easily. Proper navigation button is needed for this purpose. Generally, these buttons are put in the bottom right corners so that the operator can easily determine it. A good HMI should always have a page with entire system overview. This is important for making it easy for the operator to determine which page to be at for different segments of a large process. Navigation buttons must consist of "Next" and "Previous" functionalities.[1]

Control buttons can be used for controlling a machine through an HMI touch-screen. All the buttons should be labeled properly with enough large space to hit easily with fingers. Start, stop and mandatory operational button should be designed as **SCADA** (Supervisory Control and Data Acquisition) color convention. All the Control Buttons should be grouped together on the bottom portion of an HMI touch screen. There should be pop-up windows containing "OK" and "Cancel" with each control button in order to avoid unwanted activation which may cause danger or injury.

Page Hierarchy

A good HMI should always have a proper page hierarchy which reflects progressive exposure of more detailed information. According to the present industrial standards, the first page of an HMI is an "Overview" screen. This shows the operation of a process at a given time. Then the next pages comprise of detailed information where the actual interactions with a process occur. Page hierarchy enables operator to move down from overview to details in a logical manner. An HMI graphics hierarchy can be expressed in several levels as following[4]:

a. **Level 1:** This page contains an overview that covers the entire process control. By seeing this page operators should be, at a glance, able to tell the overall operational condition of a process for which they are responsible.
b. **Level 2:** This screen shows the sub-units of a large process. This screen should show all the information and controls necessary to perform task for each of the sub-units.

c.   **Level 3:** These pages show all the detail about each single piece of equipment or process control scheme. These screens are used for system diagnostic purposes.

d.   **Level 4:** This level shows details of subsystems, sensors or components and miscellaneous information.

Operational Security

While designing an HMI screen, security options should be taken under consideration. Security level functions are used in order to restrict user access depending on operator levels. Password protections restrict access to specific screens, such as management and maintenance screens. This helps to improve screen security which in turn ensures both machine and operator's safety.

Samples of a Bad and Good HMI Design

Below is an example of an HMI design that no way satisfies industrial standards:
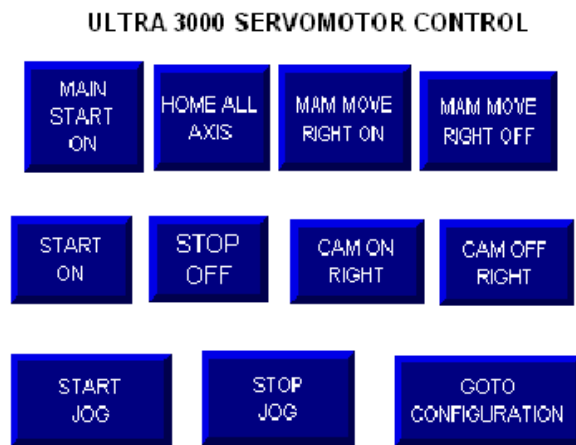

Figure 5: A Bad HMI Touch Screen Design

In comparison to the bad HMI design above, this paper shows an example of industry standard Allen-Bradley PanelView™ Plus 600 HMI Design with multiple operational screens. Here, we have performed motion control operations using Allen-Bradley Kinetix 6000, Allen-Bradley Ultra 3000 for and Allen-Bradley PowerFlex® 4.

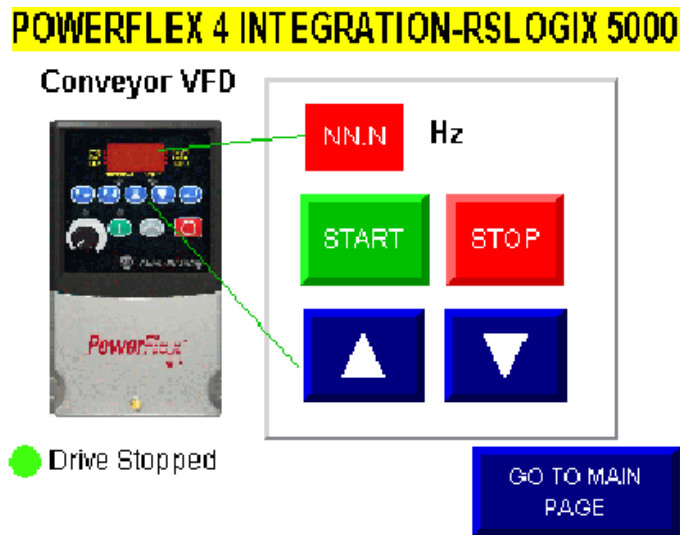**Figure 6: Allen-Bradley PanelView™ Plus 600 HMI Main Screen**

Figure 7: Motion Program Screen for Allen-Bradley
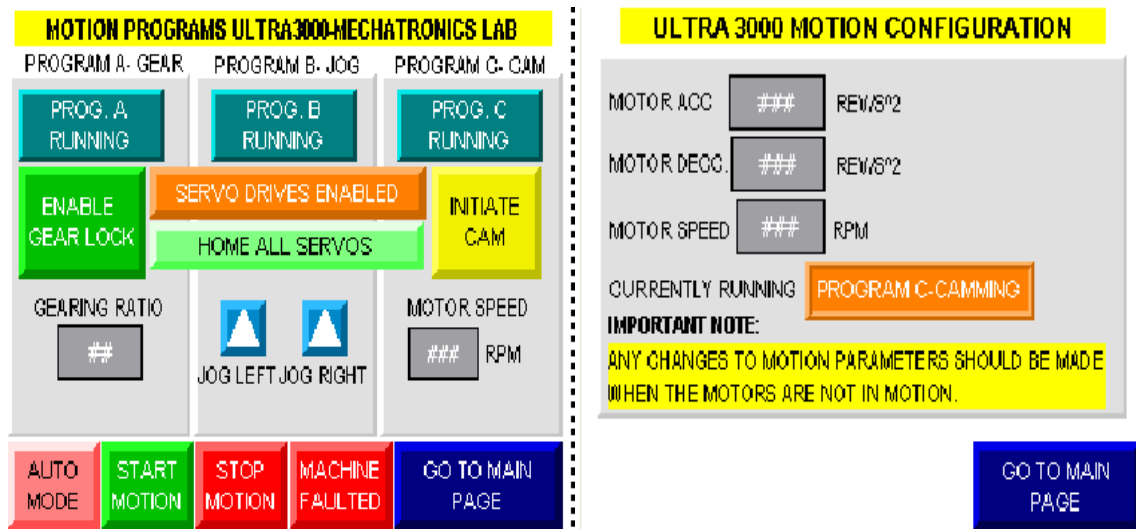
PowerFlex® 4 Conveyor Control

Figure 8: Motion Program and Motion Configuration Screen for Allen-Bradley Ultra 3000 Servo Motor Control.
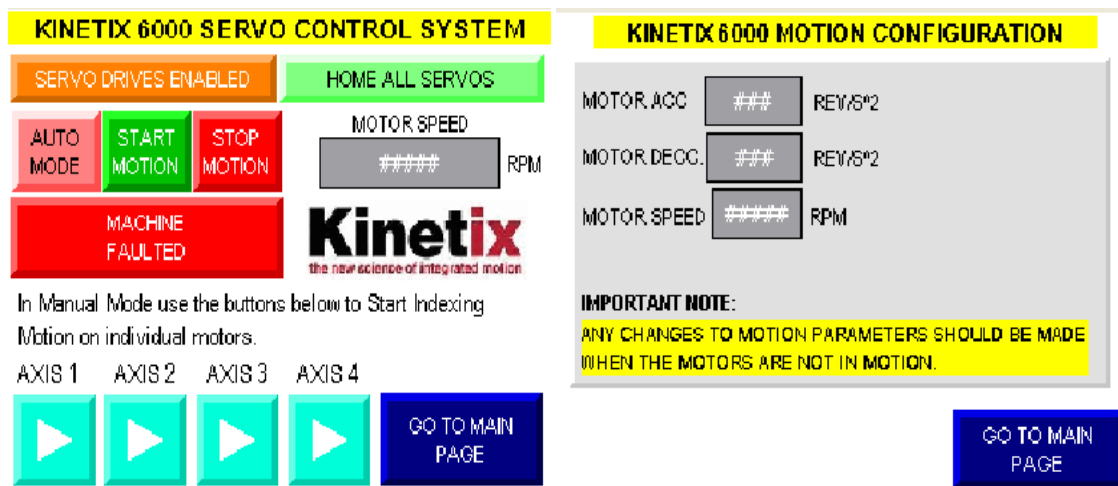

Figure 9: Motion Program and Motion Configuration Screen for Allen-Bradley Kinetix 6000 Servo Control.

Discussion of Results

The example of industrial PanelView™ Plus HMI screens that has been included in this paper is laboratory experimental designs intended to show the important approaches needed for unambiguous operator understanding. The HMI in **Figure-5** is referred to as a bad design because it does not follow any industrial standard. For example, there is no color variation in

buttons for indicating different actions, no main page providing overview of operations those are being performed; no color code has been maintained for start, stop and navigation actions.

On the other hand, in **Figure 6,** we can see an industrial standard HMI design starting with an overview page containing options for different types of motion analysis using Allen-Bradley Kinetix 6000, Allen-Bradley Ultra 3000 and Allen-Bradley PowerFlex® 4. This design enables an operator to obtain clear visual sense of different actions underneath each option. For example, if an operator goes to PowerFlex4 option he/she can successfully run or stop a conveyor with the **START** or **STOP** buttons indicated with appropriate color-code and easily readable labels. An operator can also vary the conveyor speed by only pressing the up (▲) and down (▼) buttons shown in the HMI screen. For the Allen-Bradley Ultra 3000 and Kinetix 6000, various motion statuses of servomotors are shown with values of different important parameters, such as motor speed, motor acceleration, gearing ratio etc. The screens have easily differentiable buttons with different colors and appropriate labels. In addition, proper instructions are also provided so that an operator understands which buttons should be used to achieve desired actions in different modes. In order to increase the operator friendliness, some more considerations are also taken into account such as present status of the buttons labeled with current actions, "blinking buttons" while a program is running in auto-mode, commented navigation buttons to switch to other pages for controlling other actions simultaneously while one program is running [e.g. changing servo motion program through Ultra 3000 while running conveyor with PowerFlex® 4].

Outcome for Student Learning

The main focus of the discussions on this paper is to provide control system engineering students with fundamental concepts of designing HMI screens according to industrial standards. These basics will help them to develop understandings of more operator friendly approaches further when they intend to design touch screen controls for complex automated machineries. Here, Allen-Bradley PanelView™ Plus HMI screen have been used in the examples. However, these ideas are equally applicable for HMI design with any other types of touch screens.

References:

1. "HMI Screen Examples with Allen-Bradley Panel Builder"

2. Operator Screen (HMI) Design Guidelines website: www.hexatec.com

3. "The High Performance HMI Handbook: A Comprehensive Guide to Designing, Implementing and Maintaining Effective HMIs for Industrial Plant Operations", by Bill Hollifield, Dana Oliver, Ian Nimmo, and Eddie Habibi, PAS 2008.

4. "What Your Operators Need to Know and the Best Way to Show It to Them"- http://www.controlglobal.com/articles/2011/the-ultimate-hmi.html

5. "Human-Machine Interface Design for Process Control Applications", Jean-Yves Fiset, ISA, 2009

6. Trademark Products Used in Examples: **PanelView™ Plus 600, PowerFlex® 4**